

EUCLIDIAN*

Galen Hunt & Bill Bolosky
Microsoft Research Redmond

*Environment for User-Centric, Location Independent Data and Interactive Applications

HOW WILL WE BUILD IMPOSSIBLE THINGS?

- ❑ Select an impossibly ambitious target scenario spanning fields in which we have expertise
- ❑ Build a new artifact by combining artifacts we already have with new work as needed
- ❑ Evaluate the artifact-in-progress against the target scenario.
- ❑ Re-build and re-evaluate.

WHY SHOULD MSR BUILD IMPOSSIBLE THINGS?

- To live up to our potential.

*MSR has **more talent** and **better institutional support** than any other group of researchers on the planet.*

Shouldn't we make the most of it?

WHAT SHOULD YOU DO ABOUT IT?

- Actively look for opportunities:
 - Do you have **code** or **algorithms** we could use?
 - Do you have **ideas** we should use?
 - Can Euclidian give your research better **context**?
 - Should “we” include **you**?

DISCLAIMER

- Bill and I are “systems” guys (which will taint today’s content)
- Euclidian is ***not just*** a systems project
 - if you work on **Human Computer Interaction**, Euclidian is for you.
 - if you work on **Applications**, Euclidian is for you.
 - if you work on **Hardware**, Euclidian is for you.
 - If you work on **[your research here]**, Euclidian is for you.

EUCLIDIAN

- Change the way humans interact with computation
- Three unique new properties:
 1. **physical awareness:**
computation understands the physical world outside the box
 2. **device aggregation:**
user experiences span multiple devices simultaneously
 3. **“follow-me” computing:**
applications aren’t bound to a specific machine,
but can reach out to humans wherever they are

OFFICE LABS VIDEO COLLAGE

WHY IS THIS VISION HARD?

- because our systems lack environment awareness
- because our abstractions are device centric
- because our systems know users, but not humans

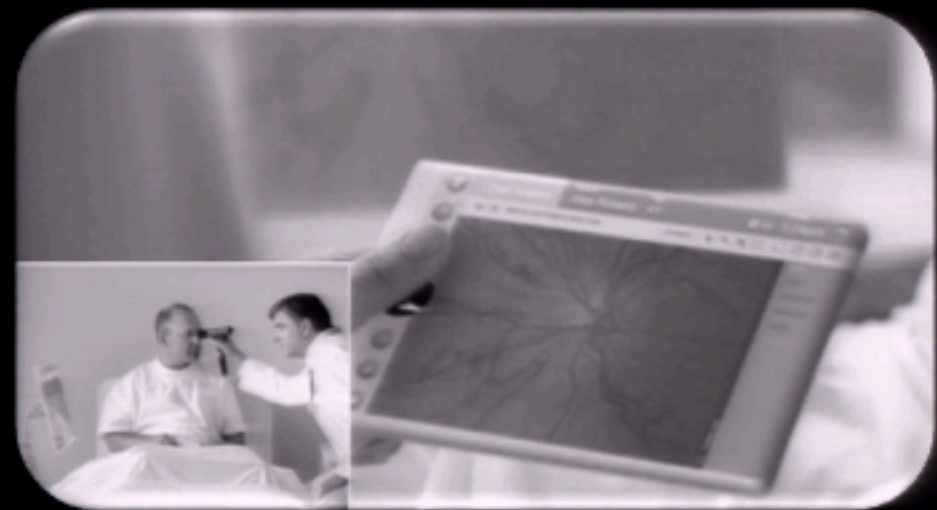
Environment Awareness



Human-Centric Security & Policy



Reuse of Non-precious Devices

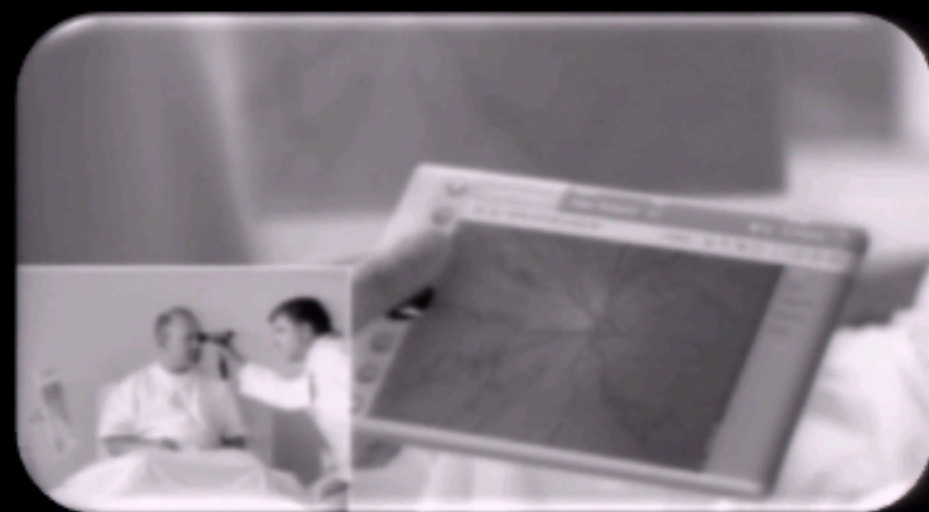


Device Aggregation

Environment Awareness



Human-Centric Security & Policy



Reuse of Non-precious Devices

Device Aggregation

Environment Awareness



Human-Centric Security & Policy



Reuse of Non-precious Devices



Device Aggregation

Environment Awareness



Human-Centric Security & Policy



Reuse of Non-precious Devices



Device Aggregation

EUCLIDIAN

- Build a new model for computing:
 - grounded in our physical world
- New applications and experiences
- New OS with new abstractions
 - physical model of humans and devices
 - user-centric I/O
 - security and naming grounded in physical world

WHY MSR?

1) MS has unique expertise and artifacts

- **Natal, Surface & Vision:** Recognition of physical world & gestures
- **Adaptive Systems:** Models of human attention and intent
- **Sensors:** Activity recognition and fine-grain location awareness
- **Cimbiosis:** Filtered, fidelity-aware data replication
- **Drawbridge:** Lightweight sandboxing with extremely cheap migration, and device aggregation built on RDP
- **[Insert your research here]**

WHY MSR?

2) We've done this sort of thing before

- **Singularity**
 - Build an OS from the ground-up with managed code
 - Apply static analysis more pervasively than any previous system
 - Use code base as point of contact for diverse research agendas
- **Success:**
 - **Collaboration:** 30+ researchers, 3 labs; OS, Languages, Tools, and Security
 - **Tech Transfer:** Windows, CLR; Midori 75+ person incubation team
 - **Scholarship:** 25+ publications and patents

EUCLIDIAN PROJECT STATUS

Project in early formation

- Defined initial systems scenarios, building team, & collecting artifacts
- Started to build enough system to begin collaboration (architecture “outlined in pencil”)
- Actively recruiting collaborators

Participants so far

- **Redmond:** Bill Bolosky, Barry Bond, Rich Draves, Jeremy Elson, Michel Goraczko, Anoop Gupta, Galen Hunt, Jie Liu, Reuben Olinsky, Karin Strauss
- **Silicon Valley:** Moises Goldszmidt, Rama Ramasubramania, Doug Terry, Ted Wobber,
- **Cambridge:** Shahram Izadi, Otmar Hilliges
- **Asia:** Baining Guo

EUCLIDIAN MILESTONE 1

- First implementation of
 - device aggregation
 - physical awareness
 - *but, nothing else ...*
- Skeleton system as seed for collaboration
- System is real enough that an “intern” can modify the bouncing ball demonstration to run under Euclidian in a day.

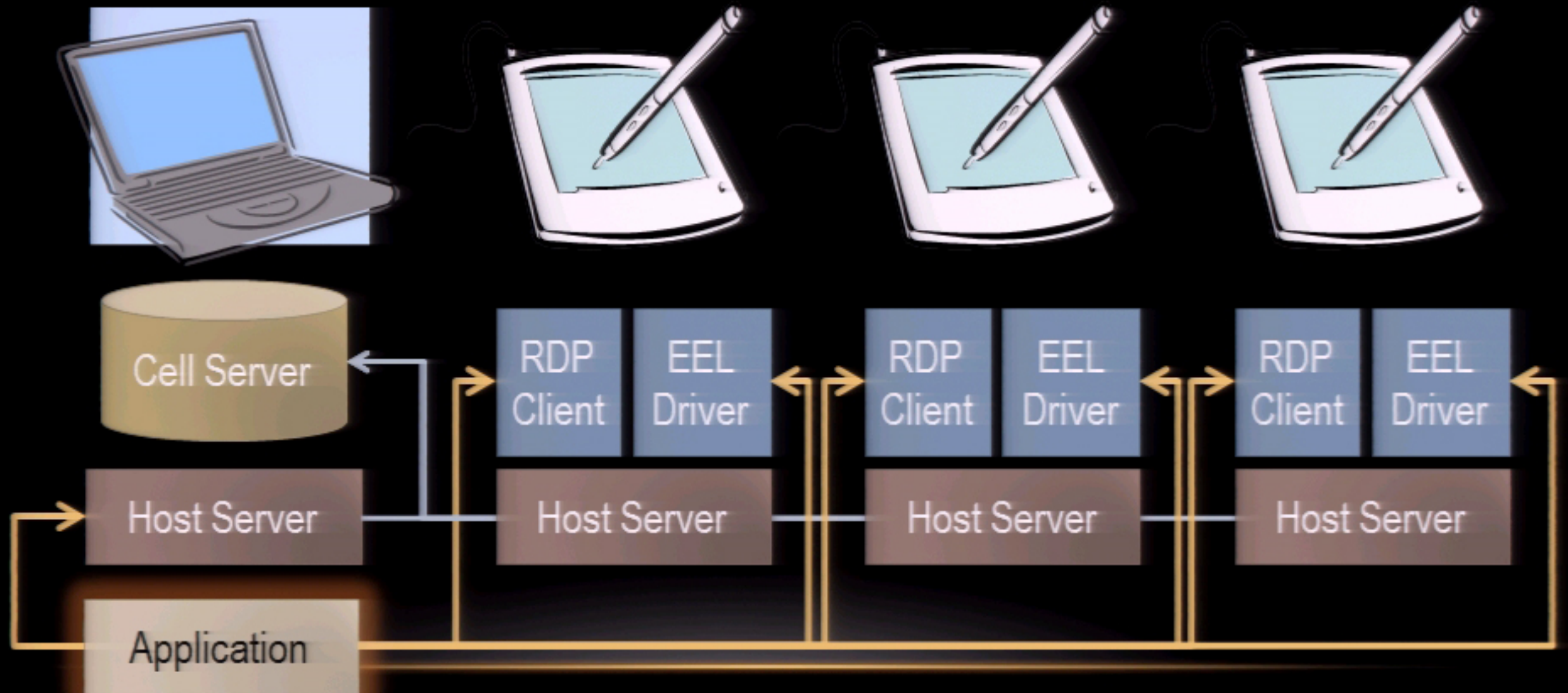


BOUNCING BALL DEMO

M1 STATUS (TRUTH IN ADVERTISING)

- What's there
 - Primitive service for locating devices
 - Drivers for a few simple devices
 - Primitive non-dimensional model of universe
 - Encapsulated application with Euclidian version of Win32 using Drawbridge
- What's not there
 - Awareness of humans
 - Usable 3-d model of universe
 - State or application management
 - Security, attention, or prioritization
 - Applications
 - etc., etc., etc.

M1 ARCHITECTURE



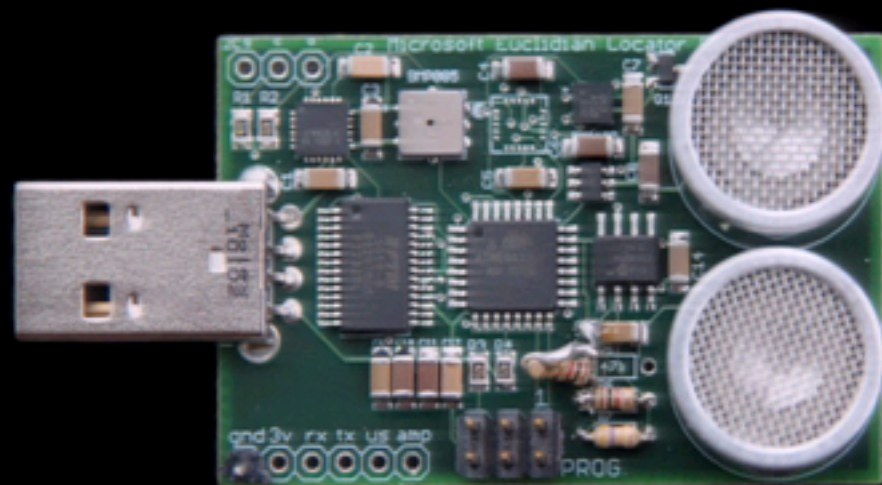
M1 CODE SAMPLE

```
euclidian->GetNeighbors(application, RoleDisplay, &displays);

nDisplays = displays->GetCount();
for (int i = 0; i < nDisplays; i++) {
    displays->GetEntityInterface(displays, i, &display);
    display->AddToRunningApplication();

    euclidian->GetNeighbors(display, RoleAccelerometer, &accelerometers);
    if (accelerometers->GetCount() > 0) {
        accelerometers->GetEntityInterface(accelerometers, i, &accelerometer);
    }
}
```


ELSON EUCLIDIAN LOCATOR (EEL)



- First of many devices to provide physical awareness to Euclidian
- Sensors include:
 - Ultrasonic transducers for acoustic time-of-flight ranging
 - 3D accelerometer, gyroscope, and compass
 - Barometric altimeter

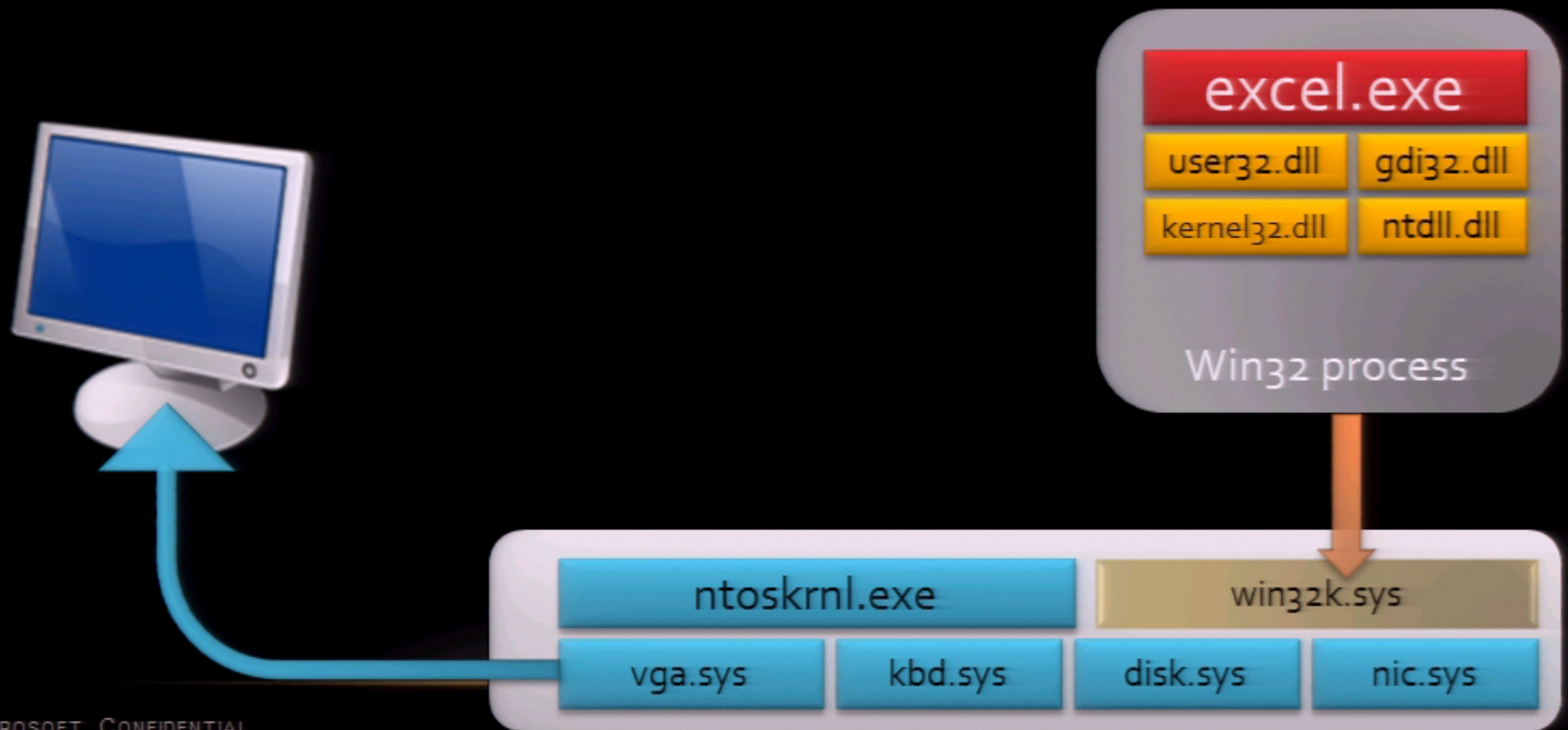
BUILDING A NEW OS FOR EUCLIDIAN

- ... well, OK, we actually plan to refactor Windows
- Our strategy:
 - reuse as much of Windows as we can
 - but, dramatically refactor it into a new distributed system

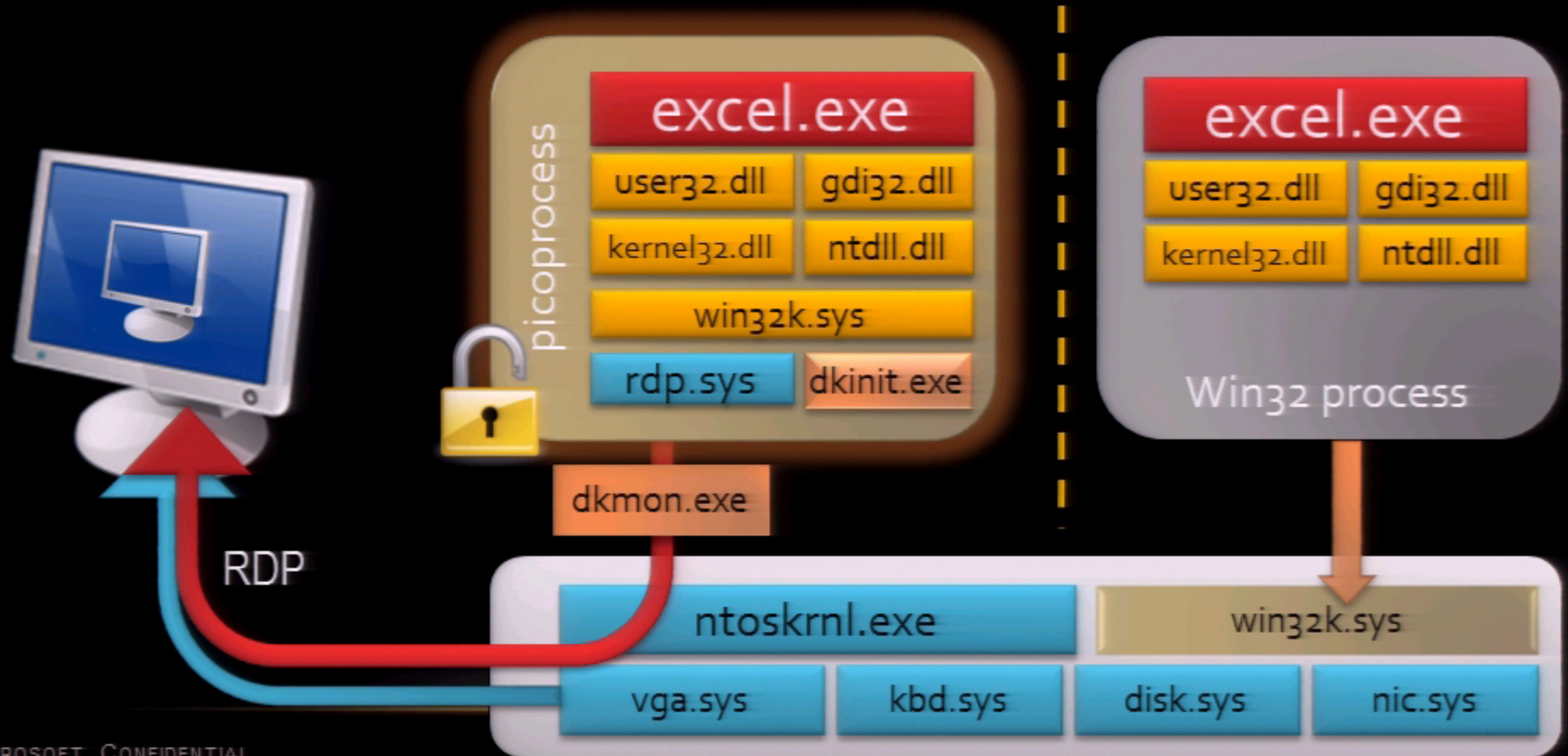
DRAWBRIDGE

- Private sandboxed subset of Windows
- *Picoprocess* isolation unit contains
 - application
 - win32 subsystem
 - RDP server
- Enables
 - **secure isolation**: can't get out of its sandbox
 - **legacy compatibility**: runs private version of Windows APIs
 - **migration**: move from one computer to another on demand
 - at 1% the cost of a virtual machine.

DRAWBRIDGE ARCHITECTURE

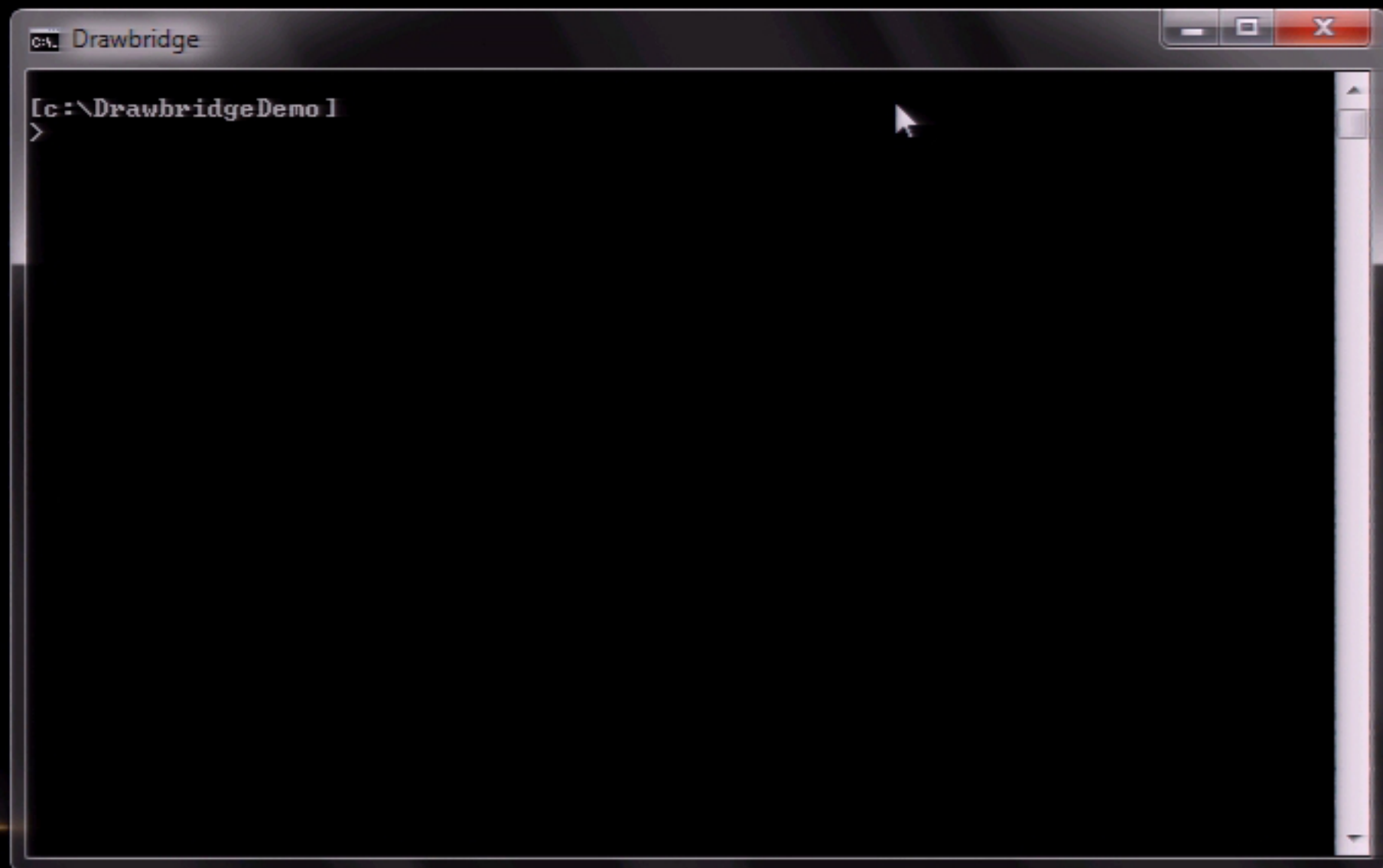


DRAWBRIDGE ARCHITECTURE



DRAWBRIDGE DEMO

DRAWBRIDGE DEMO



MICROSOFT CONFIDENTIAL

27

DRAWBRIDGE DEMO

```
C:\> Drawbridge - rv

[c:\DrawbridgeDemo]
>rv

[c:\DrawbridgeDemo\reversi]
>dkmon.exe -m reversi.manifest reversi.exe
MSR Project Drawbridge Monitor [Jul 15 2010 14:33:15]

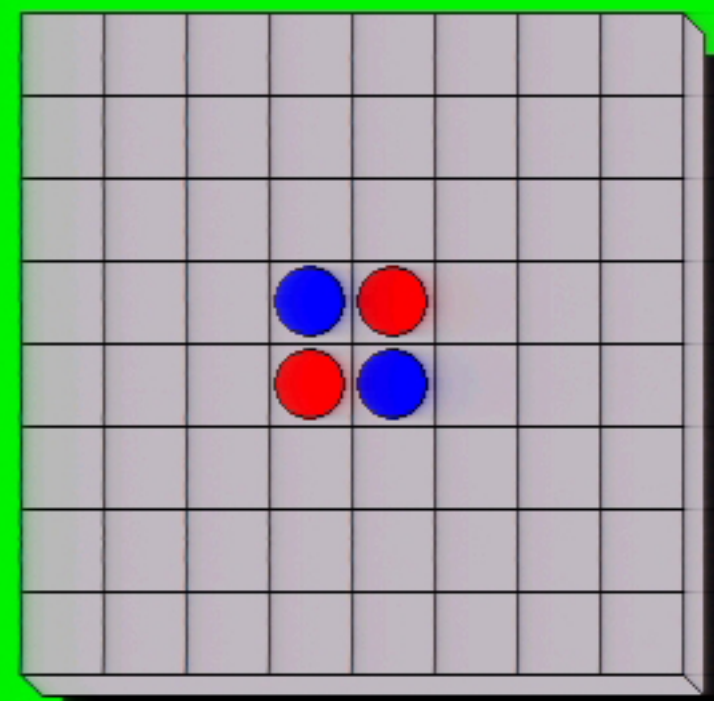
dkmon: Starting [reversi.exe] with [dkinit.exe]
DkMonitor>      \??\c:\DrawbridgeDemo\reversi\reversi.manifest
--  \??\c:\DrawbridgeDemo\reversi\default.reg
    \??\c:\DrawbridgeDemo\reversi\kernel32.dll
    \??\c:\DrawbridgeDemo\reversi\KERNELBASE.dll
    \??\c:\DrawbridgeDemo\reversi\locale.nls
    \??\c:\DrawbridgeDemo\reversi\win32k.dll
    \??\c:\DrawbridgeDemo\reversi\msvcrt.dll
    \??\c:\DrawbridgeDemo\reversi\RDPVDD.dll
    \??\c:\DrawbridgeDemo\reversi\RDP4US.dll
    \??\c:\DrawbridgeDemo\reversi\user32.dll
    \??\c:\DrawbridgeDemo\reversi\GDI32.dll
    \??\c:\DrawbridgeDemo\reversi\FONTS.FON
    \??\c:\DrawbridgeDemo\reversi\en-US\win32k.dll.mui
    \??\c:\DrawbridgeDemo\reversi\UGASYS.FON
    \??\c:\DrawbridgeDemo\reversi\OEMFONT.FON
    \??\c:\DrawbridgeDemo\reversi\UGAOEM.FON
    \??\c:\DrawbridgeDemo\reversi\FIXEDFON.FON
    \??\c:\DrawbridgeDemo\reversi\UGAFIX.FON
    \??\c:\DrawbridgeDemo\reversi\SSERIFE.FON
    \??\c:\DrawbridgeDemo\reversi\UGASYS.FON
    \??\c:\DrawbridgeDemo\reversi\en-US\user32.dll.mui
    \??\c:\DrawbridgeDemo\reversi\reversi.exe
```

MICROSOFT CONFIDENTIAL

27

Reversi

Game Skill Help



14:33:15
xel
reversi.manifest
eg
ll
.dll

2k.dll.mui
ON
ON

\\c:\drawbridgedemo\reversi\SSERIFE.FON
\\c:\drawbridgedemo\reversi\UGASYS.FON
\\c:\drawbridgedemo\reversi\en-US\user32.dll.mui
\\c:\drawbridgedemo\reversi\reversi.exe

c
Launching RDP client.
Loading client on pipe "\\.\pipe\db-reversi"
DkMonitor>

MICROSOFT CONFIDENTIAL

27

DRAWBRIDGE DEMO

```
C:\> Drawbridge - rv

[c:\DrawbridgeDemo\reversi\
>dkmon.exe -m reversi.manifest reversi.exe
MSR Project Drawbridge Monitor [Jul 15 2010 14:33:15]

dkmon: Starting [reversi.exe] with [dkinit.exe]
DkMonitor>      \??\c:\DrawbridgeDemo\reversi\reversi.manifest
--      \??\c:\DrawbridgeDemo\reversi\default.reg
      \??\c:\DrawbridgeDemo\reversi\kernel32.dll
      \??\c:\DrawbridgeDemo\reversi\KERNELBASE.dll
      \??\c:\DrawbridgeDemo\reversi\localization
      \??\c:\DrawbridgeDemo\reversi\win32k.dll
      \??\c:\DrawbridgeDemo\reversi\msvcrt.dll
      \??\c:\DrawbridgeDemo\reversi\RDP4US.dll
      \??\c:\DrawbridgeDemo\reversi\RDP4US.dll
      \??\c:\DrawbridgeDemo\reversi\user32.dll
      \??\c:\DrawbridgeDemo\reversi\GDI32.dll
      \??\c:\DrawbridgeDemo\reversi\FONTS.FON
      \??\c:\DrawbridgeDemo\reversi\en-US\win32k.dll.mui
      \??\c:\DrawbridgeDemo\reversi\UGASYS.FON
      \??\c:\DrawbridgeDemo\reversi\OEMFONT.FON
      \??\c:\DrawbridgeDemo\reversi\UGAOEM.FON
      \??\c:\DrawbridgeDemo\reversi\FIXEDFON.FON
      \??\c:\DrawbridgeDemo\reversi\UGAFIX.FON
      \??\c:\DrawbridgeDemo\reversi\SSERIFE.FON
      \??\c:\DrawbridgeDemo\reversi\UGASYS.FON
      \??\c:\DrawbridgeDemo\reversi\en-US\user32.dll.mui
      \??\c:\DrawbridgeDemo\reversi\reversi.exe

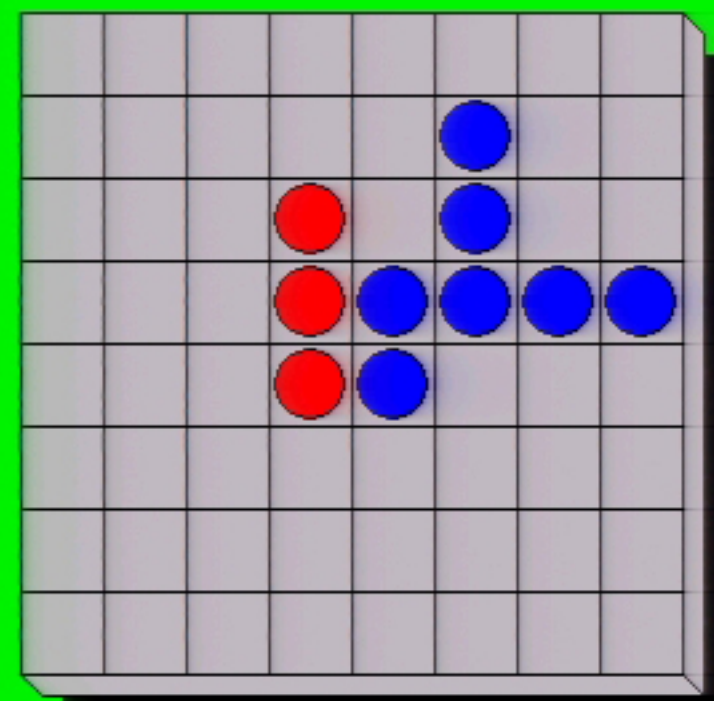
c

Launching RDP client.
Loading client on pipe "\\.\pipe\db-reversi"
DkMonitor> c
```

MICROSOFT CONFIDENTIAL

Reversi

Game Skill Help



```
xe1
\reversi.manifest
eg
ll
.dll
2k.dll.mui
ON
ON
ON
32.dll.mui
e
```

```
C
Launching RDP client.
Loading client on pipe "\\.\pipe\db-reversi"
DkMonitor> c

Launching RDP client.
Loading client on pipe "\\.\pipe\db-reversi"
DkMonitor>
```

MICROSOFT CONFIDENTIAL

27

DRAWBRIDGE DEMO

```
C:\> Drawbridge

\\??\c:\DrawbridgeDemo\reversi\KERNELBASE.dll
\\??\c:\DrawbridgeDemo\reversi\locale.nls
\\??\c:\DrawbridgeDemo\reversi\win32k.dll
\\??\c:\DrawbridgeDemo\reversi\msvcrt.dll
\\??\c:\DrawbridgeDemo\reversi\RDP4US.dll
\\??\c:\DrawbridgeDemo\reversi\RDP4US.dll
\\??\c:\DrawbridgeDemo\reversi\user32.dll
\\??\c:\DrawbridgeDemo\reversi\GDI32.dll
\\??\c:\DrawbridgeDemo\reversi\FONTS.FON
\\??\c:\DrawbridgeDemo\reversi\en-US\win32k.dll.mui
\\??\c:\DrawbridgeDemo\reversi\UGASYS.FON
\\??\c:\DrawbridgeDemo\reversi\OEMFONT.FON
\\??\c:\DrawbridgeDemo\reversi\UGAOEM.FON
\\??\c:\DrawbridgeDemo\reversi\FIXEDFON.FON
\\??\c:\DrawbridgeDemo\reversi\UGAFIX.FON
\\??\c:\DrawbridgeDemo\reversi\SSERIFE.FON
\\??\c:\DrawbridgeDemo\reversi\UGASYS.FON
\\??\c:\DrawbridgeDemo\reversi\en-US\user32.dll.mui
\\??\c:\DrawbridgeDemo\reversi\reversi.exe

c
Launching RDP client.
Loading client on pipe "\\.\pipe\db-reversi"
DkMonitor> c

Launching RDP client.
Loading client on pipe "\\.\pipe\db-reversi"
DkMonitor> q
Terminating monitor...

[c:\DrawbridgeDemo]
>
```

MICROSOFT CONFIDENTIAL

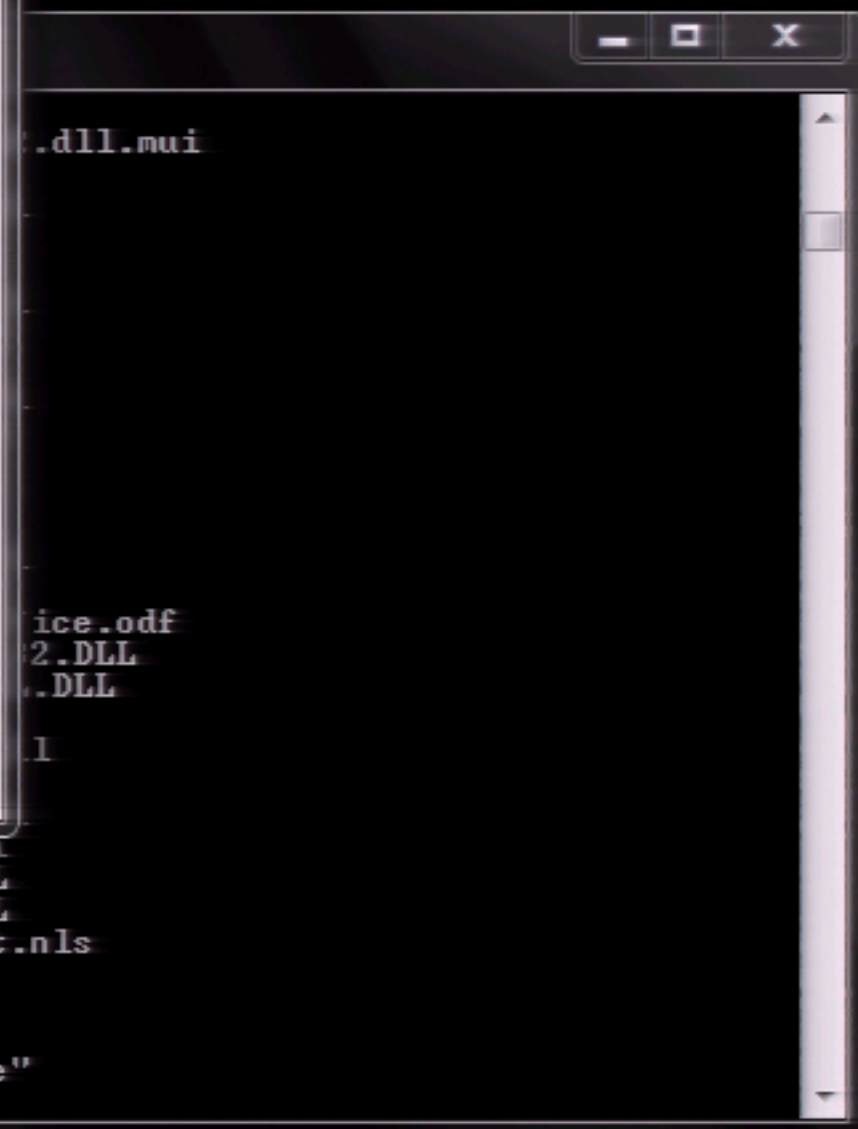
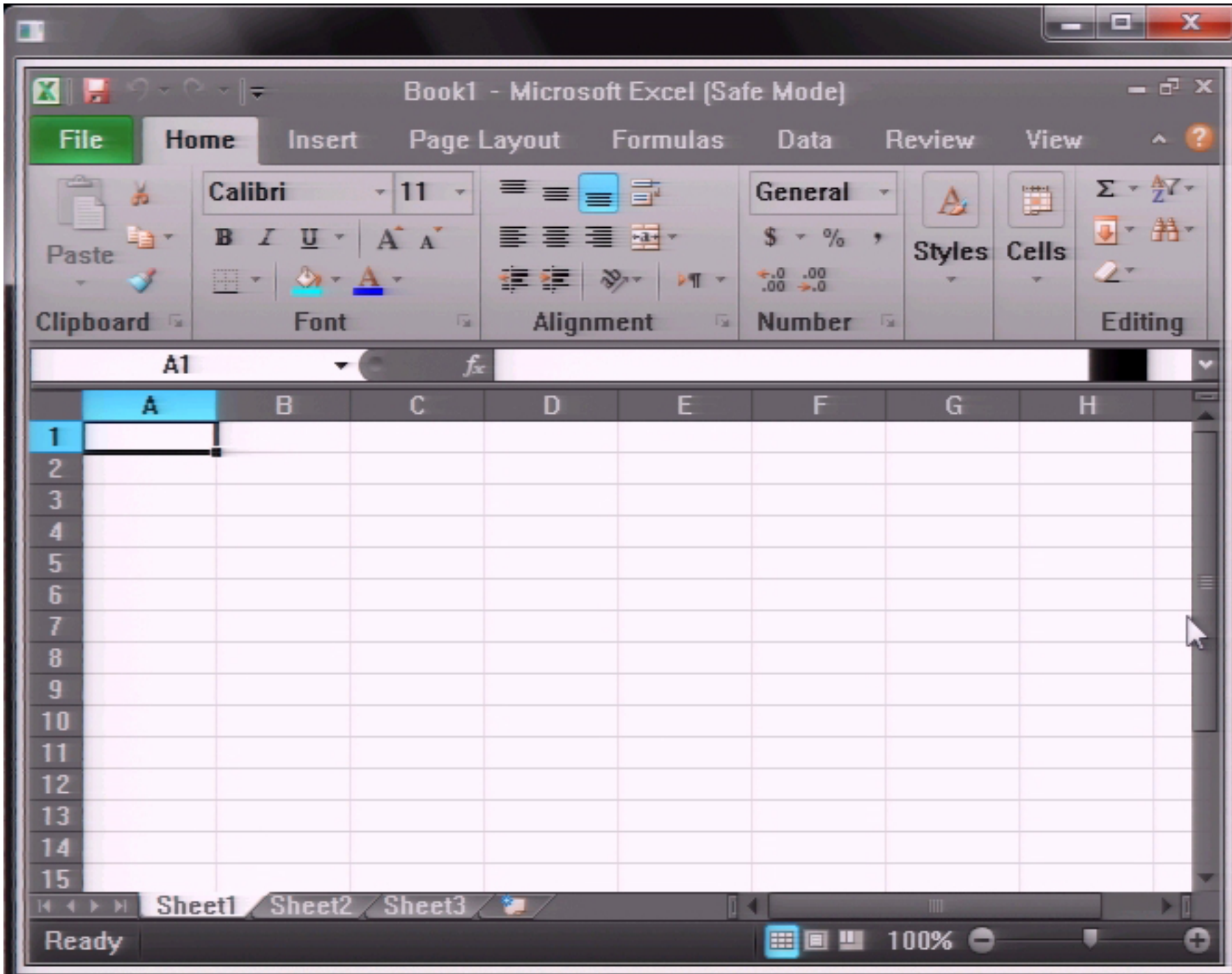
27

DRAWBRIDGE DEMO

```
Drawbridge - ex
\\??\c:\DrawbridgeDemo\excel\UGAOEM.FON
\\??\c:\DrawbridgeDemo\excel\FIXEDFON.FON
\\??\c:\DrawbridgeDemo\excel\UGAFIX.FON
\\??\c:\DrawbridgeDemo\excel\SSERIFE.FON
\\??\c:\DrawbridgeDemo\excel\UGASYS.FON
\\??\c:\DrawbridgeDemo\excel\en-US\user32.dll.mui
\\??\c:\DrawbridgeDemo\excel\excel.exe
\\??\c:\DrawbridgeDemo\excel\ADUAPI32.dll
\\??\c:\DrawbridgeDemo\excel\ole32.dll
\\??\c:\DrawbridgeDemo\excel\RPCRT4.dll
\\??\c:\DrawbridgeDemo\excel\OLEAUT32.dll
\\??\c:\DrawbridgeDemo\excel\MSUCR90.dll
\\??\c:\DrawbridgeDemo\excel\gfx.dll
\\??\c:\DrawbridgeDemo\excel\WTSAPI32.dll
\\??\c:\DrawbridgeDemo\excel\MSIMG32.dll
\\??\c:\DrawbridgeDemo\excel\oart.dll
\\??\c:\DrawbridgeDemo\excel\mso.dll
\\??\c:\DrawbridgeDemo\excel\msi.dll
\\??\c:\DrawbridgeDemo\excel\Comctl32.dll
\\??\c:\DrawbridgeDemo\excel\SHLWAPI.dll
\\??\c:\DrawbridgeDemo\excel\Cultures\office.odf
\\??\c:\DrawbridgeDemo\excel\1033\XLINTL32.DLL
\\??\c:\DrawbridgeDemo\excel\1033\MSOINTL.DLL
\\??\c:\DrawbridgeDemo\excel\MSORES.DLL
\\??\c:\DrawbridgeDemo\excel\CRYPTBASE.dll
\\??\c:\DrawbridgeDemo\excel\DwmApi.DLL
\\??\c:\DrawbridgeDemo\excel\riched20.dll
\\??\c:\DrawbridgeDemo\excel\GdiPlus.dll
\\??\c:\DrawbridgeDemo\excel\UxTheme.DLL
\\??\c:\DrawbridgeDemo\excel\SHELL32.DLL
\\??\c:\DrawbridgeDemo\excel\sortdefault.nls
```

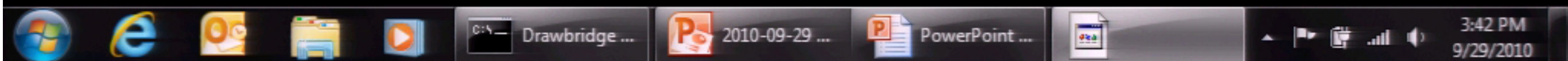
MICROSOFT CONFIDENTIAL

27



MICROSOFT CONFIDENTIAL

27



DRAWBRIDGE DEMO

```
C:\> Drawbridge - ex

\\??\c:\DrawbridgeDemo\excel\UGASYS.FON
\\??\c:\DrawbridgeDemo\excel\en-US\user32.dll.mui
\\??\c:\DrawbridgeDemo\excel\excel.exe
\\??\c:\DrawbridgeDemo\excel\ADVAPI32.dll
\\??\c:\DrawbridgeDemo\excel\ole32.dll
\\??\c:\DrawbridgeDemo\excel\RPCRT4.dll
\\??\c:\DrawbridgeDemo\excel\OLEAUT32.dll
\\??\c:\DrawbridgeDemo\excel\MSUCR90.dll
\\??\c:\DrawbridgeDemo\excel\gfx.dll
\\??\c:\DrawbridgeDemo\excel\WTSAPI32.dll
\\??\c:\DrawbridgeDemo\excel\MSIMG32.dll
\\??\c:\DrawbridgeDemo\excel\oart.dll
\\??\c:\DrawbridgeDemo\excel\mso.dll
\\??\c:\DrawbridgeDemo\excel\msi.dll
\\??\c:\DrawbridgeDemo\excel\Comctl32.dll
\\??\c:\DrawbridgeDemo\excel\SHLWAPI.dll
\\??\c:\DrawbridgeDemo\excel\Cultures\office.odf
\\??\c:\DrawbridgeDemo\excel\1033\XLINTL32.DLL
\\??\c:\DrawbridgeDemo\excel\1033\MSOINTL.DLL
\\??\c:\DrawbridgeDemo\excel\MSORES.DLL
\\??\c:\DrawbridgeDemo\excel\CRYPTBASE.dll
\\??\c:\DrawbridgeDemo\excel\DwmApi.DLL
\\??\c:\DrawbridgeDemo\excel\riched20.dll
\\??\c:\DrawbridgeDemo\excel\GdiPlus.dll
\\??\c:\DrawbridgeDemo\excel\UxTheme.DLL
\\??\c:\DrawbridgeDemo\excel\SHELL32.DLL
\\??\c:\DrawbridgeDemo\excel\sortdefault.nls

c
Launching RDP client.
Loading client on pipe "\\.\pipe\db-office"
DkMonitor> _
```

MICROSOFT CONFIDENTIAL

27

COMPLEXITY OF REFACTORING

Component	Original Size	Code Changed	% Chg	#if's
excel	2.8 MLoC	278 LoC	0.01%	102
powerpnt	2.8 MLoC	280 LoC	0.01%	102
reversi	1.2 KLoC	0 Loc	0.00%	0
ole32	318 KLoC	482 LoC	0.15%	125
rpcrt4	174 KLoC	2 LoC	0.00%	1
gdi32	56 KLoC	389 LoC	0.69%	20
win32k	389 KLoC	5,962 LoC	1.53%	769
rdp4vs	97 KLoC	13 LoC	0.01%	1

TO WHAT END?

- Drawbridge in Euclidian enables
 - Location-independent access to multiple UX devices
 - “Follow-me” migration of applications between computers
 - Low-friction path forward from Windows to Euclidian

OPEN QUESTIONS

- **APPLICATIONS AND USER EXPERIENCE**

- What is the user interface for systems and applications that can simultaneously span multiple devices with physical awareness (not just screens, but a wide range of other sensors and actuators as well including cameras, microphones, speakers, accelerometers, etc.)?
- How can an application interface scale gracefully (say from a 3" phone display to multiple displays with a keyboard and mouse to multiple walls)?
- How might awareness of the physical environment in applications enable better collaboration between users in a shared physical space?
- How does an application simultaneously and effectively interact with multiple users?
- Is there some low impact way to modify existing applications effectively to use multiple displays or scalable user interfaces?
- What new applications does Euclidian enable?

- **SENSORS AND PHYSICAL AWARENESS**

- What sensors and software across sensors can provide the richest range of interactions between users and computing at affordable price points?
- How should data from various sensors be combined in a scalable manner to provide a coherent view of the physical environment (for example to provide fine-grained position and trajectory information about physical objects from accelerometers, ultra-sound sensors, and cameras)?

- **SECURITY**

- What is the desired security model and how is trust established and maintained between applications, users, and devices in a Euclidian environment (particular in light of the desire that devices become non-precious)?
- How is user privacy managed in an environment in which computers are aware of the physical environment?
- Should the user interface include physical information security (for example to redact salary information on my screen if a non-privileged user enters the room)?

- **SYSTEMS**

- What are the best APIs and abstraction for exposing the physical environment in a user-centric manner to applications?
- What policies should determine where to run applications or place data in a distributed system with a rich user interface model?
- How can a distributed system enable rich interactive user interfaces while providing multi-device and location-independent computing?
- How should data and applications be named and stored in a user-centric, location-independent system?
- How can Euclidian enable moving running applications from computer to computer to follow the user?
- Are there practical distributed programming models that might allow Euclidian applications to easily incorporate computation on multiple computers?
- How are resources effectively shared among users and applications?

- **[Insert your research here.]**

HOW DO YOU PARTICIPATE?

- Collaboration organized around cooperating, independent research
 - focus on your own research agenda
 - in context of shared vision, programs, solutions, and effort
- Shared artifact code base:
 - others help you succeed (by contributing their work through code)
 - you help others succeed (by contributing your working code to artifact)
- Collaborative decision-making: the “design note” process
 - four levels (as needed): principles, architecture, implementation, usage
 - documented to improve onboarding and insure forward progress
 - “benevolent despot” calls consensus

CALL TO ACTION: GET INVOLVED

- Ask questions:
 - <mailto:euclidi> (or talk to Galen and Bill)
- Read the OneNote and Design Notes:
 - <http://euclidian>
- Check out the current artifact (and add your code):
 - See *Euclidian Design Note 1* for instructions to enlist, build, and run
- Join the discussion:
 - Design Discussions: Thursdays, 3pm, 99/3050
 - Standing Status Meetings: (Bi-weekly, TBD)